

SCENES IN STEINMETZ HALL AT THE
NEW YORK WORLD'S FAIR

10,000,000-volt Sparks and 1,000,000-volt Arcs

GENERAL ELECTRIC HIGH-VOLTAGE EXHIBIT AT NEW YORK WORLD'S FAIR

Equipment for producing the high-voltage demonstrations – Impulse generator, high-voltage transformers and associated equipment – Means of control – Operation – Power supply for lighting and auxiliaries

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THE General Electric Exhibition building at the New York World's Fair is divided into the "House of Magic," the Exhibit Hall, and Steinmetz Hall.

It is in Steinmetz Hall that the much-talked-of displays of man-made lightning and other high-voltage phenomena are exhibited. Though the observation gallery has a capacity for an audience of 600, the number of people attracted to the exhibit is so great that the demonstrations have to be repeated some 20 times a day to accommodate as many different groups of visitors. As of October 1, over 4000 such demonstrations have been given.

The principal elements of the high-voltage apparatus in the Hall are two 5,000,000-volt impulse generators and a three-phase 60-cycle 1,000,000-volt transformer set. The floor space is 65 ft by 116 ft by 55 ft to the tie rods under the roof. The gallery floor is about 10 ft above the main floor, 15 ft from the million-volt transmission lines between the transformers and the spark gap, and 27 ft from the impulse generators. It is protected by a wood wainscot, plate glass above this, and then by a series of small cables stretched horizontally above the glass. There are no windows in the Hall because the exhibition is best-seen in the dark; but many spotlights with thyratron control are used.

To prevent the electric discharges from interfering with near-by radio and television demonstrations, the walls and roof are completely sheathed inside and out with sheet copper. The grounding system is thorough, consisting of a wire net buried 2½ ft underground and a number of 50- to 90-ft hollow steel piles driven far below ground-water level. The low-voltage circuits are protected against surges by capacitors and Thyrite surge resistors.

The two impulse generators occupy the foreground, one on each side, and between them are the three masts for the revolving three-phase-arc electrodes. The high-voltage transformers and operating balcony are in the background, and the kenotron set for charging the impulse generator is directly in front of the balcony.

The motor-generator set which supplies power to the transformers that produce the million-volt three-phase arcs is below and behind the gallery in an outside room having one wall entirely of glass, so that it is fully visible from without. Here too are located

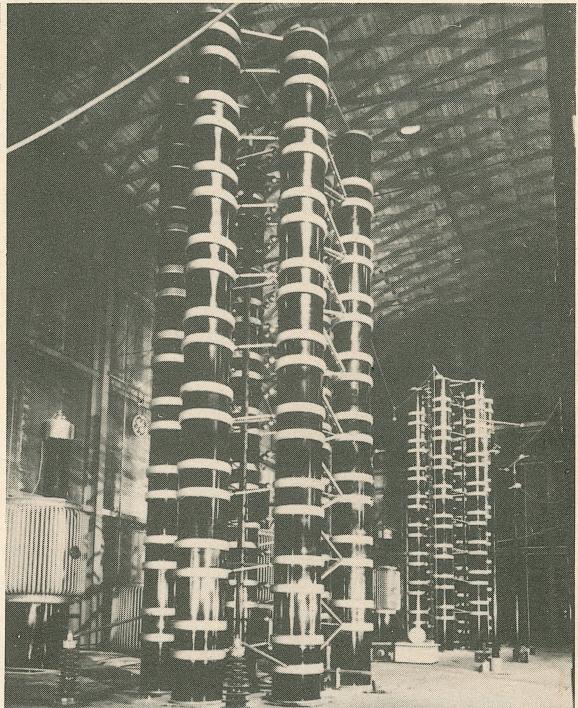


Fig. 1. View in Steinmetz Hall showing (in the foreground and to the right) the impulse generator that produces the 10,000,000-volt sparks and (in the left-and-center background) the transformers that produce the 1,000,000-volt three-phase arcs

seven Pyranol distribution transformers that supply power for lighting and for small motors in the building.

PRODUCTION OF 10,000,000-VOLT DISCHARGES

While used at the World's Fair for display purposes, the impulse generator installed in Steinmetz Hall is representative of modern laboratory or industrial design, and similar equipments may be seen in daily operation for research and the making of commercial tests on a wide variety of apparatus manufactured at the Philadelphia and Pittsfield plants of the General Electric Co.

Built in two units, each capable of delivering a maximum of 5,000,000 volts, the set is operated with the two in series, one at each polarity, the neutral point being grounded. This arrangement results in a maximum rating of 10,000,000 volts for the two units, with minimum clearances to ground and surroundings. In this respect it differs from a conventional commercial installation, where tests to ground are required

and potentials in the order of 3,000,000 volts are usually sufficient.

Each 5,000,000-volt assembly is made up of 51 capacitor units assembled in six vertical columns. Each of the capacitor units is rated 100,000 volts, 0.33 microfarad. These units are connected in groups of three horizontally and, starting at the ground end, all these groups are connected in parallel through resistors for charging at 300,000 volts dc by a kenotron rectifier. Progressing upward in the stack, each group is connected in series through a ball spark gap with the one which precedes it; thus at the instant the discharge is initiated at the ground gap, the series circuit is closed in a few millionths of a second and the total voltage of the groups appears at the line electrode.

The six columns of capacitors are supported on a structural steel base, hexagonal in shape, which also forms the support for the sphere gaps and their operating mechanism, as shown in FIG. 1.

The bottom capacitor of the first column is insulated for 150,000 volts above ground and is supported by a Herkolite insulating cylinder which is of the same diameter as the capacitor and which is mechanically fastened to it and to the base. The remaining five units at the base of the other columns are similarly supported, with the lengths of the cylinders increasing in increments corresponding to the voltage added at each position in the series. This gives a vertical pitch to the entire assembly but does not affect the lengths of the intermediate spacing cylinders, which are all identical.

Although commonly termed a helix, the circuit as actually connected takes the form of a figure 8 during the discharge. Such a form has several advantages, readily apparent: the inductance of the discharge

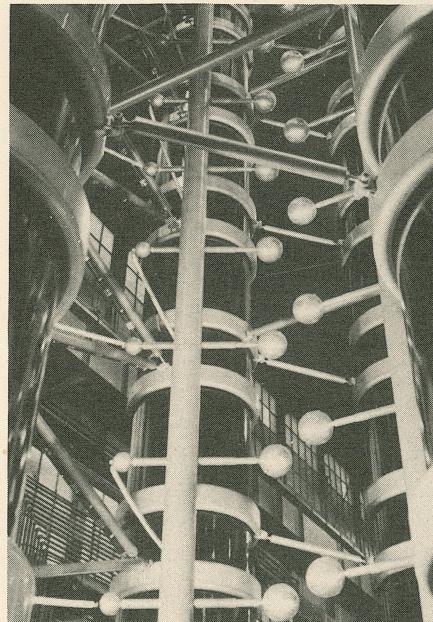


Fig. 2. A close-up between the capacitor columns of one of the impulse-generator units

circuit is lower than for a helix; the resistors can be connected in a convenient zig-zag manner directly above each other up the stack of the complete generator; and the gaps are then placed entirely inside the assembly where all are mounted on a single pair of Herkolite tubes, one tube being adjustable for the variable spacing required for different excitation.

Each column consists of interspaced capacitor units and supporting insulating cylinders, and the complete structure is rigidly tied together and braced by the charging resistors and the bar conductors which connect the three capacitors in series for each bank. The generator is an extremely compact unit and free from the usual mass of supporting structure required where the conventional type of capacitor is used.

A novel, but simple, type of corona-shield construction is used at each junction of capacitor and cylinder. Bolted to each end of the capacitor and to

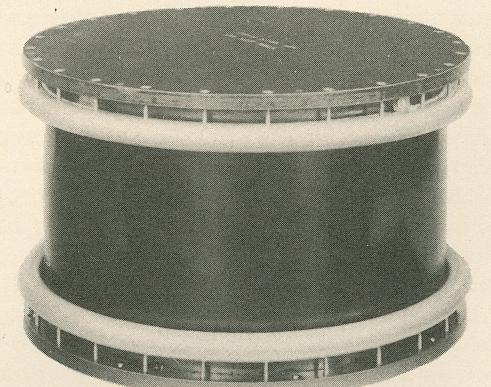


Fig. 3. A 100,000-volt 0.33-microfarad Pyranol capacitor, of which there are 102 in the impulse generator

each end of the cylinder is a welded steel-pipe ring, nickel plated. When these units are assembled their ends are bolted together and the rings and the space between them are covered by a stainless-steel corona-shielding band. The shielding bands are shown in FIG. 2 and the pipe rings in FIG. 3.

The parallel charging resistors consist of wire-wound vitreous-enamel units assembled in Herkolite tubes spaced to withstand the impulse voltage between individual groups at the time of impulse discharge and to fit mechanically between the vertical sections of the capacitor columns, which are connected in parallel for charging. Thus the resistor assembly performs the double function of both an electrical and mechanical tie between capacitor groups and columns.

Capacitors

The capacitor units (FIG. 3) are of a design developed especially for impulse testing equipment. Each is assembled in an insulating Herkolite case, vacuum treated, and filled with Pyranol. The cover and base, also of Herkolite insulation, are each clamped to the case in such a manner as to form a liquid-tight joint. The clamping rings used also form the two terminals of the capacitor, thus eliminating the use of projecting bushings and giving full utilization of the

tank surface as an insulator, which is not possible with a metal case.

Extremely strong in construction, this capacitor unit is readily adapted to a vertical stack assembly and needs no additional means of support.

Charging Equipment

The generator is charged from a 300,000-volt d-c source consisting of two full-wave bridge-connected kenotron rectifiers operated in series, with the midpoint grounded. The elementary connections are shown in FIG. 4. The voltage selected (300,000 volts) was convenient to obtain from two rectifiers and sufficiently high to keep the series gaps at a reasonable number. Full-wave operation was desirable in order that a relatively large capacitance could be charged in the minimum time.

The rectifier units are cross-connected to the two generator stacks through charging resistors and the two are charged in parallel but at opposite polarities. This limits the potential of each capacitor group to 150,000 volts above ground during the charging period, and assists in making possible a simple means for initiating the discharge.

Voltage control of the rectifier is obtained through a motor-operated induction voltage regulator having a voltage range of 100 per cent raise and lower. The instantaneous charging current of the generator is limited both by series charging resistors and reactors in the main power supply.

The rectifier, reactors, regulator, and automatic discharge switch are mounted on the main floor and are remote controlled from the operating gallery, directly above. On this gallery is installed a benchboard-type panel, with complete controls for the main and auxiliary circuits, including those of the regulator, series gaps, initiating gaps, and kenotron filament. Each rectifier circuit is equipped with a crest voltmeter calibrated directly in kilovolts dc and provided with a d-c ammeter to indicate charging current. Thus the operator can determine, at any time during the operating cycle, the condition of charge of the generator.

Initiation Circuit

The initiation of the generator impulse is accomplished by connecting, by means of a variable spark gap, electrically operated, the line terminals of the first capacitor banks of each 5,000,000-volt stack.

As stated earlier, the positive and negative ends respectively of each three-unit bank at the ground end of the separate stacks are normally isolated from ground by a sphere gap and when the capacitors are fully charged the potential across this gap is 150,000 volts. FIG. 4 shows that, when the generator initiating gap is closed, the combined voltage of the two 300,000-volt sections is brought across the two ground gaps in series. With the spark-over of these gaps, the terminal voltage of the capacitors immediately shifts from 150,000 volts to 300,000 volts on one stack and to equal but opposite potential on the other, thus increasing the voltage on the connecting gaps between

the first and second banks of each stack and causing them to "fire"; this is repeated until all capacitors are connected in series in a few millionths of a second and the total voltage appears across the discharge rod gaps as shown at the top in the FRONTISPICE.

The electrically operated initiating gap is operated either by a manual control switch on the main panel or by a synchronous timer set for predetermined times of charge and discharge.

Since no measurements of wave form or other characteristics are required for exhibition purposes, no voltage divider nor control resistors are necessary, but these are readily added and are an essential part of similar generators used for research and commercial tests.

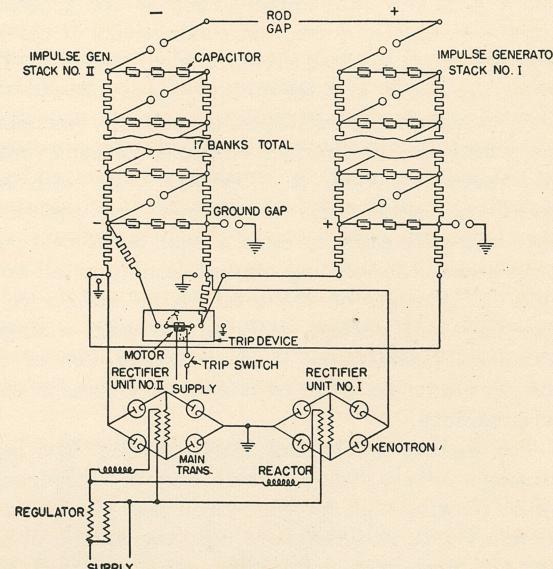


Fig. 4. Connection diagram of the impulse generator and its associated equipment

General Characteristics

The series capacitance of each 5,000,000-volt unit is 0.00653 microfarad and the equivalent discharge energy 81.6 kw-sec, which is 163 kw-sec for the two generators in series. The inductance of the complete discharge circuit is in the order of 300 microhenrys and the total resistance is approximately 22 ohms. The discharge current is of the order of 22,000 amperes.

PRODUCTION OF 1,000,000-VOLT THREE-PHASE 60-CYCLE POWER ARCS

The 1,000,000-volt three-phase power arc takes place between three spinner electrodes, which are caused to revolve by the action of corona discharge.

The motor-generator that energizes the three-phase-arc transformers consists of a 1500-hp synchronous motor direct coupled to a 1500-kw sine-wave generator of low synchronous impedance (70 per cent) with motor and generator excitors direct coupled at the ends. There is an automatic regulator for the motor field, to maintain high power factor. The generator voltage is varied by rheostats in the exciter and generator fields. Both these rheostats are

controlled from the benchboard in the operating gallery. A schematic diagram of connections is shown in FIG. 5.

A power-limiting reactor of 13.5 per cent, connected in the generator leads to the transformers, limits the current to about twice normal at quarter voltage, the arc acting as a partial short circuit. When the arc strikes, the character of the load changes suddenly from open-circuit leading current to short-circuit lagging current. The power factor at the generator under load may be about 25 to 40 per cent lagging. A million-volt three-phase arc load is shown at the bottom in the FRONTISPICE.

It is not practical to give exact values of voltage, current, and power as they are constantly varying and depend on many factors, such as the generator excitation, length of arc, and conductivity of the gas from the chemicals used to color the arc, and so on. The action associated with the discharge is as follows:

As the generator excitation is gradually increased from zero, the transformer terminal voltage eventually reaches 850,000 to 1,000,000 volts with low excitation because the transformer and connected lines and spark gaps represent a small but almost pure capacitance, the exciting current leading at all voltages. This reacts on the total circuit inductance to give high line voltage, sufficient to start a single-phase arc between the sharp points of two of the spinner electrodes when by chance they come in closest proximity.

The current of the two loaded phases then lags, causing a voltage drop, but the voltage of the unloaded phase remains high for the reason just given and it therefore arcs to somewhere near the middle of the first arc, thus producing a three-phase arc in T formation. A typical example is shown in FIG. 6.

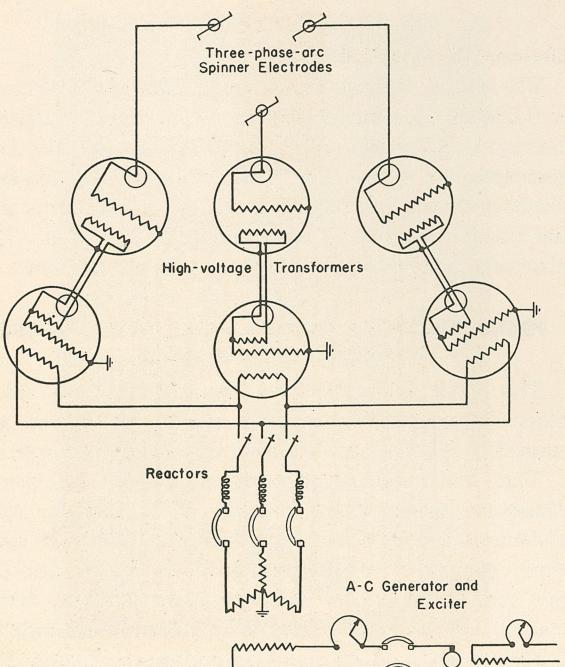


Fig. 5. Connection diagram of the three-phase-arc transformers and associated alternator equipment

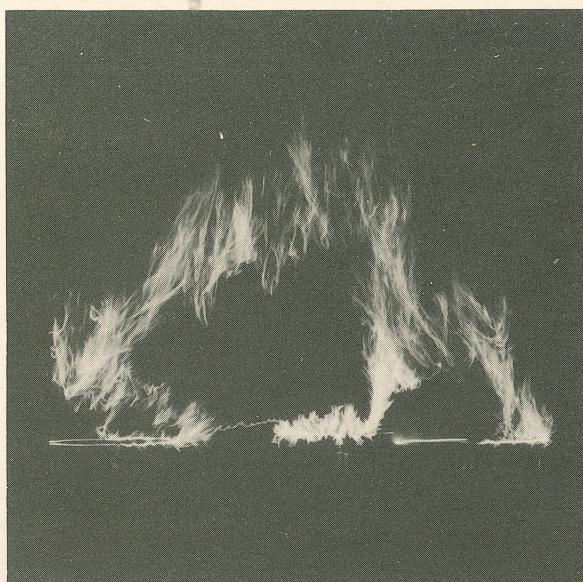


Fig. 6. A view of the three-phase colored arcs between spinner electrodes

High-voltage Transformers

The three-phase power arc is produced by six transformers, each rated 350,000 volts, and with a continuous rating of 1000 kva, connected two in series in each leg of a Y, for 700,000 volts from line to grounded neutral, or 1,200,000 volts between lines. These transformers are of a type originated for transformers that were to operate under extremely severe conditions. This type, now standard for high-power low-reactance testing transformers, represents a great advance over previous designs.

As shown in FIG. 7, one unit of each leg stands on the ground and the other on a Herkolite cylinder 5 ft high to insulate the tank of the latter for 350,000 volts to ground.

The grounded unit contains a third winding the purpose of which is to excite the insulated or line unit. This third winding has a rating of 2300 volts, 500 kva, and is connected to the high-voltage winding at the line end (FIG. 5).

The other terminal of the third winding is brought out through the center of the common high-voltage terminal, but is insulated from it. From this point two single-conductor cables transfer the excitation to the low-voltage terminals of the insulated or line unit.

The continuous normal power rating of these transformers is:

	RATINGS IN KVA		
	Low-voltage Winding	Excitation Winding	High-voltage Winding
Grounded Transformer	1500	500	1000
Insulated or Line Transformer.....	1000	...	1000

These 350,000-volt units (FIG. 8) of 1000 kw continuous rating have less than half the size (tank only) and two-thirds the weight of units of the

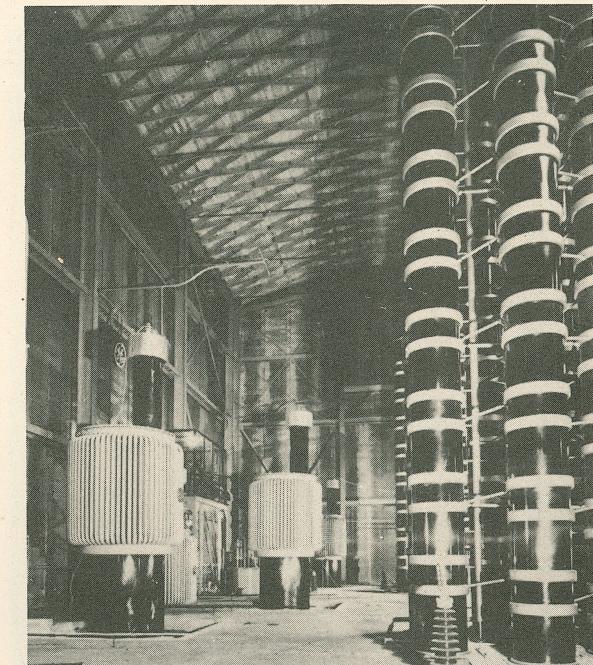


Fig. 7. Another view in Steinmetz Hall, showing (at the right) the impulse-generator units and (at the left) the high-voltage-arc transformers

previous type, for 350 kw one-hour rating; and they also have lower reactance and losses.

The size of the units is indicated by the following dimensions:

Tank diameter (inside)..... 65 in.
Tank diameter (over tubes)..... 85½ in.
Tank height (over cover)..... 92¾ in.
Tank height (over terminal)..... 14 ft 10½ in.

Tests. Transformer units of this design withstand an induced voltage of 450,000 volts and an impulse of 1,300,000 volts, either being sufficient to arc over the terminal without injury. FIG. 9(a) shows a laboratory test arc-over at 450,000 volts and FIG. 9(b) a laboratory impulse test at over 1,300,000 volts.

Core and Windings. A vertical three-leg core is used, with all the circular windings around the cruciform-section middle leg. The core clamps are of steel channels throughout, that for the top yoke serving to bolt the whole assembly to the cover, as shown in FIG. 10.

The coils are cylindrical in form with the high-voltage winding placed concentrically between two low-voltage windings, thus obtaining low reactance.

The coils comprising the high-voltage winding are each wound on a separate Herkolite cylinder. One end of the high-voltage winding is brought to the high-voltage terminal; the other end is brought out to a film cutout on the cover and "grounded" on the tank.

The low-voltage winding (FIG. 10) is of helical construction, in which the rectangular conductors are wound on vertical spacing strips and separated by insulating pieces to give oil circulation on all four sides of the conductor.

Shielding. In service, testing transformers are subjected to short circuits, 60-cycle arcs at full voltage, high-frequency arcs, and high-voltage impulses of

great intensity, all without external protection of any kind. These severe conditions might result in the failure of ordinary constructions, and require a transformer particularly designed to withstand them indefinitely. The windings are so arranged and shielded as to control the distribution of surge voltages, which, if excessive, will simply cause the high-voltage terminal to arc over, harmlessly, thus protecting the windings and insulation.

The regular daily service at Steinmetz Hall is probably the most exacting and severe that a testing transformer has ever been required to withstand.

Cooling. The ventilating ducts are so arranged as to enable the oil to circulate freely, and thus exceptionally effective cooling is obtained. The tank cooling surface is supplemented by three rows of two-inch tubes.

Tank Fittings. The main oil valve is at the bottom, entirely internal and operated from the cover. The valve is placed inside to avoid projections which might lead to arc-over to ground from the insulated unit. An auxiliary stopcock is placed at the top, for emptying the terminal or for connection to a filter. A thermometer is mounted at the top of the tank, just below the cover.

The cover carries the high- and low-voltage terminals, a voltmeter terminal board, and the outlet valve stem, all bolted on oiltight gaskets, the bolt holes being blind to prevent leaks.

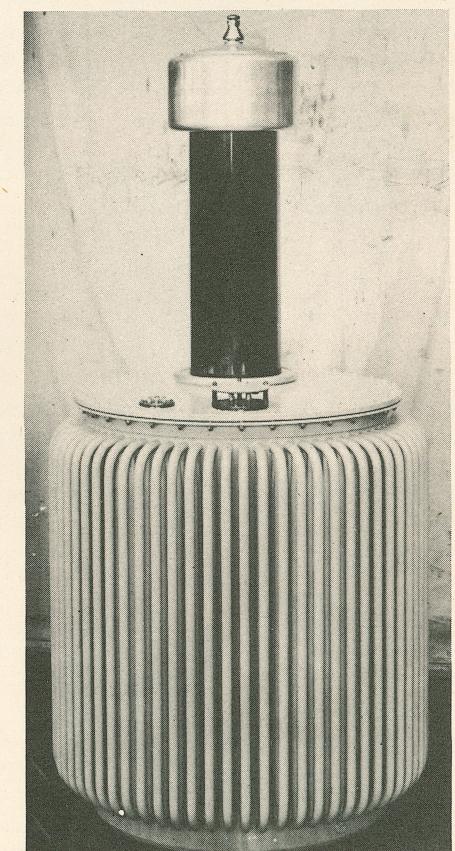


Fig. 8. One of the high-voltage transformers that are shown in position in FIG. 7

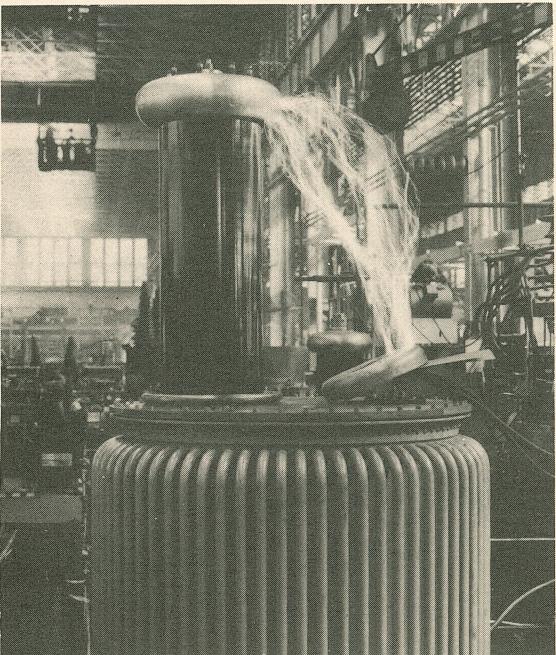


Fig. 9(a). This 450,000-volt arc over the bushing of a 350,000-volt testing transformer of the modern type demonstrates the dielectric strength of the internal insulation and the protection afforded by the bushing

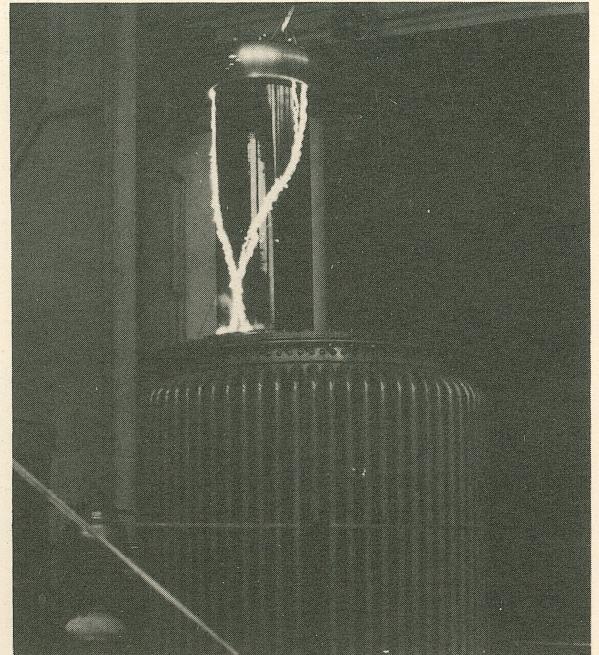


Fig. 9(b). A demonstration similar to that in Fig. 9(a) except made with a 1,300,000-volt impulse discharge

The low-voltage terminal board has four studs with links for series-parallel connection and is protected by an insulating plate covered by a steel plate.

The voltmeter terminal board has binding posts for connecting to the transformer voltmeter coil and for inserting an ammeter directly in the high-voltage circuit at the grounded end. The ammeter is paralleled

by the film cutout, which is normally insulated to puncture at less than 500 volts. The voltmeter coil is protected by a fuse in series mounted on the terminal board, and by a Thyrite surge arrester in parallel, mounted under it.

High-voltage Terminal. The lower end of the high-voltage terminal is open so that the same body of oil fills both transformer and terminal, the oil level being in the expansion tank that forms the terminal cap. It is vented in an inverted funnel at the top. The oil gage is of novel design, expressly to fulfill the requirements of reliability, visibility, freedom from leaks, and freedom from corona.

Spark Gaps

Spark gaps are mounted on three insulating masts 18 ft high, placed at the corners of an equilateral triangle 14 ft on a side. These masts are arranged to move vertically inside 10-in. steel pipes, 20 ft long, which in turn are placed in 50-ft hollow steel piles driven in the ground.

The masts are located and guided inside the pipes by ball-bearing spring-supported rollers and moved vertically by a chain and motor-driven worm-gearred drum. It is thus possible to drop the masts into the ground and out of the way while the impulse generator is in action, and then to elevate them to full height for use in the three-phase arc exhibition.

Mounted on the top of each mast is the spark-gap point proper, formed by a spinner electrode which is a horizontal bar supported at the middle by a vertical ball-bearing spindle and carrying a five-inch ball at each end. Directed tangentially from each ball is a sharp-pointed half tube suitable for holding a colored

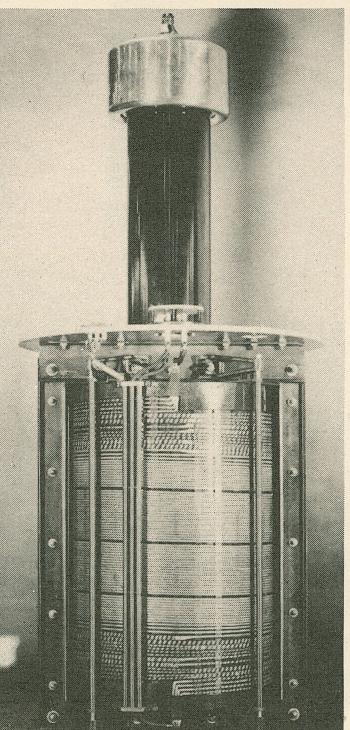


Fig. 10. The high-voltage transformer shown in Fig. 8 as it appeared before being placed in its tank

fusee. These fusees are ignited by the arc which forms between the points and serve to color the arc and also to increase its conductivity and length.

The spinners are a development of the old "Hamilton reaction mill" originally used on glass-plate electrostatic machines. Under high voltage, a powerful brush discharge is given off by the points and the repulsion between the points and the similarly charged air is a considerable force which quickly accelerates the spinner to rapid revolution.

There are two interchangeable sets of spinners 3 ft and 5 ft long between ball centers and they revolve at about 100 or 50 rpm respectively. The maximum speed is attained at about 500,000 volts to ground or 870,000 volts three-phase, as above this voltage the reaction tends to become radial rather than tangential. The shortest possible gap, or nearest approach of the arcing points, is 9 ft for the 5-ft spinner or 11 ft for the 3-ft, corresponding to approximately 850,000 to 1,000,000 volts to start the arc.

The arc rises 20 ft or more above the gap in a tortuous path estimated to be 100 to 150 ft long from point to point before breaking, when it reforms instantly.

AUXILIARY POWER TRANSFORMERS

Also on display in an adjacent part of the building are seven 200-kva Pyranol transformers (FIG. 11), which are connected to the 2400-volt distribution system of the fairgrounds, to provide 240/120-volt three-wire power for lighting and for small motors throughout the whole General Electric exhibit.

These units are standard Pyranol transformers hermetically sealed and equipped with standard accessories for such transformers, which include Pyranol level indicating gages, Pyranol sampling and drain valves, and pressure relief diaphragms.

The Electrical Code has recognized the noninflammable and nonexplosive qualities of Pyranol by allowing transformers filled with this insulating medium to be installed in a building without many of the restrictions applying to oil-filled transformers. It was therefore possible to install these transformers adjacent to the load center with only a glass partition or a simple metal fence or grill surrounding them, thus obviating the necessity of an expensive fireproof vault.

This installation of transformers located back of a glass partition for the inspection of the public furnishes a good example of the savings which can be made by the use of Pyranol transformers—savings in space as well as in cost. If oil-filled transformers had

been used, they would either have had to be housed in a fireproof vault inside the building or have been placed outside the building. In the first alternative, a large expense would have been incurred in the construction of a vault heavy enough to comply with the requirements of the National Electrical Code for such installations. Because of the necessarily limited space for each building in the grounds, it is doubtful if sufficient room for such a vault could have been obtained without seriously reducing the space available for other parts of the exhibit. In the other alternative, long, expensive runs of secondary copper would have been necessary. In addition, the external appearance of the exhibit would have been impaired.

Because Pyranol transformers made long secondary runs unnecessary, there was not only a saving in the

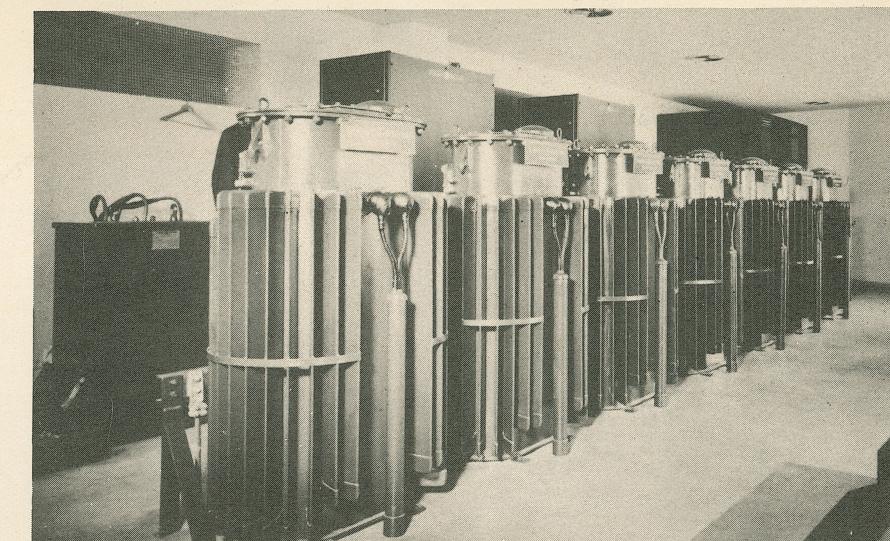
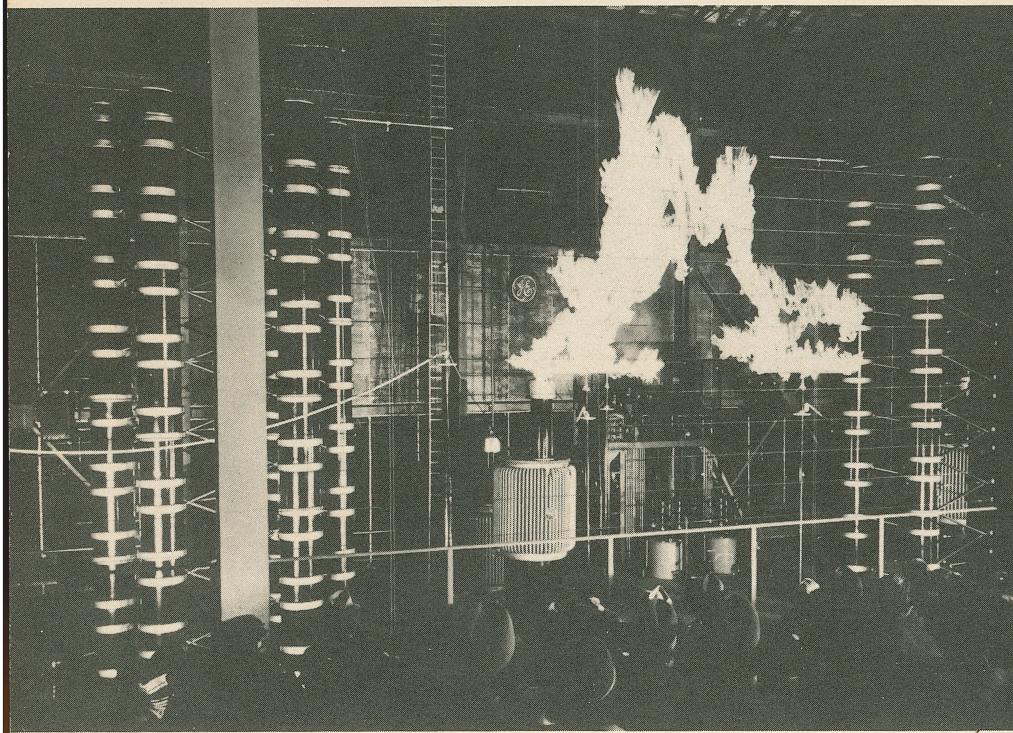
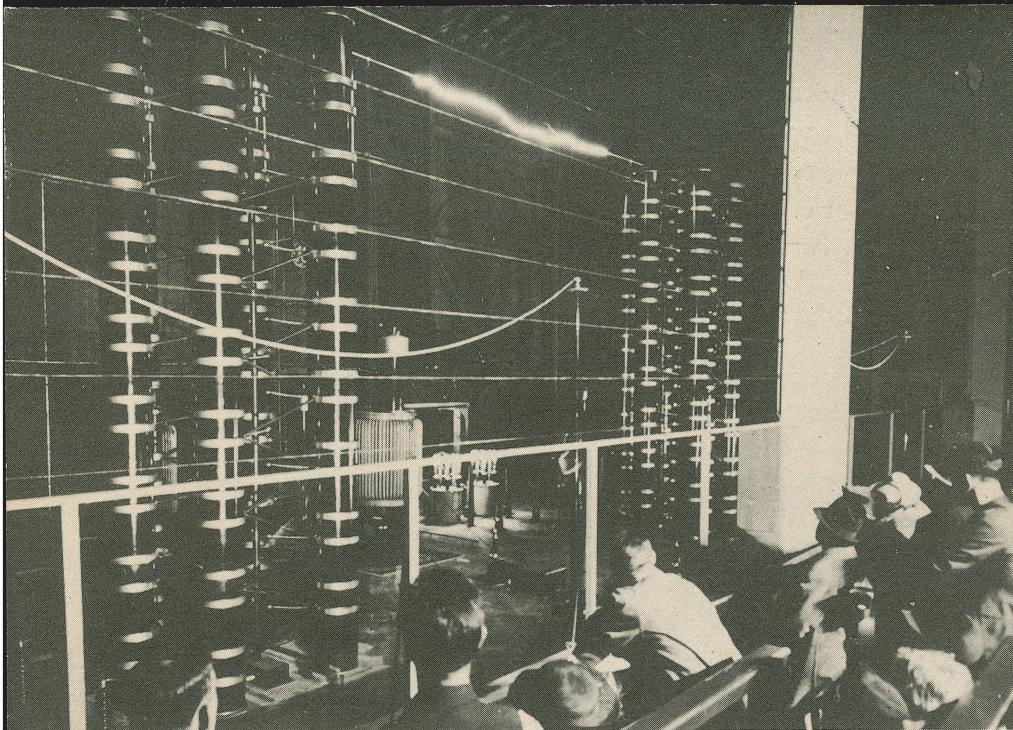


Fig. 11. Bank of seven 200-kva Pyranol transformers located in the exhibit building to furnish current for lighting and the operation of small motors

cost of the copper but also a reduction in over-all losses and an improvement in voltage regulation and efficiencies.

Thus, while these Pyranol transformers themselves serve as part of the exhibit of modern electric equipment, and serve also the purely utilitarian function of supplying the exhibit building's low-voltage electrical requirements, their location close to the load center of the building is a demonstration of the installation advantages made possible by this new type of transformer.

The remaining apparatus in Steinmetz Hall—including the impulse generator and high-voltage transformers—likewise represents in many respects the design of commercial equipment used in the most modern high-voltage industrial laboratories to investigate high-voltage phenomena. Thus, while in the Hall it serves merely the purpose of putting on a spectacular demonstration, it is of the same type as that utilized for furthering progress in high-voltage engineering, and no doubt after the Fair will find some application to research or commercial testing.



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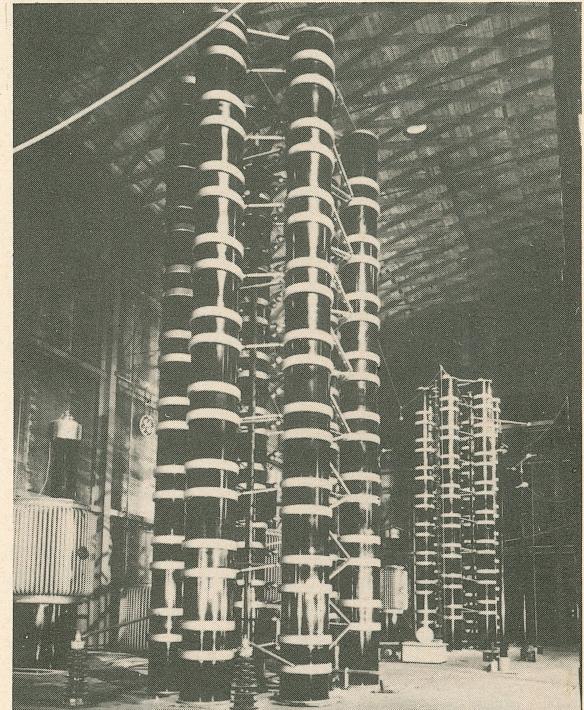


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